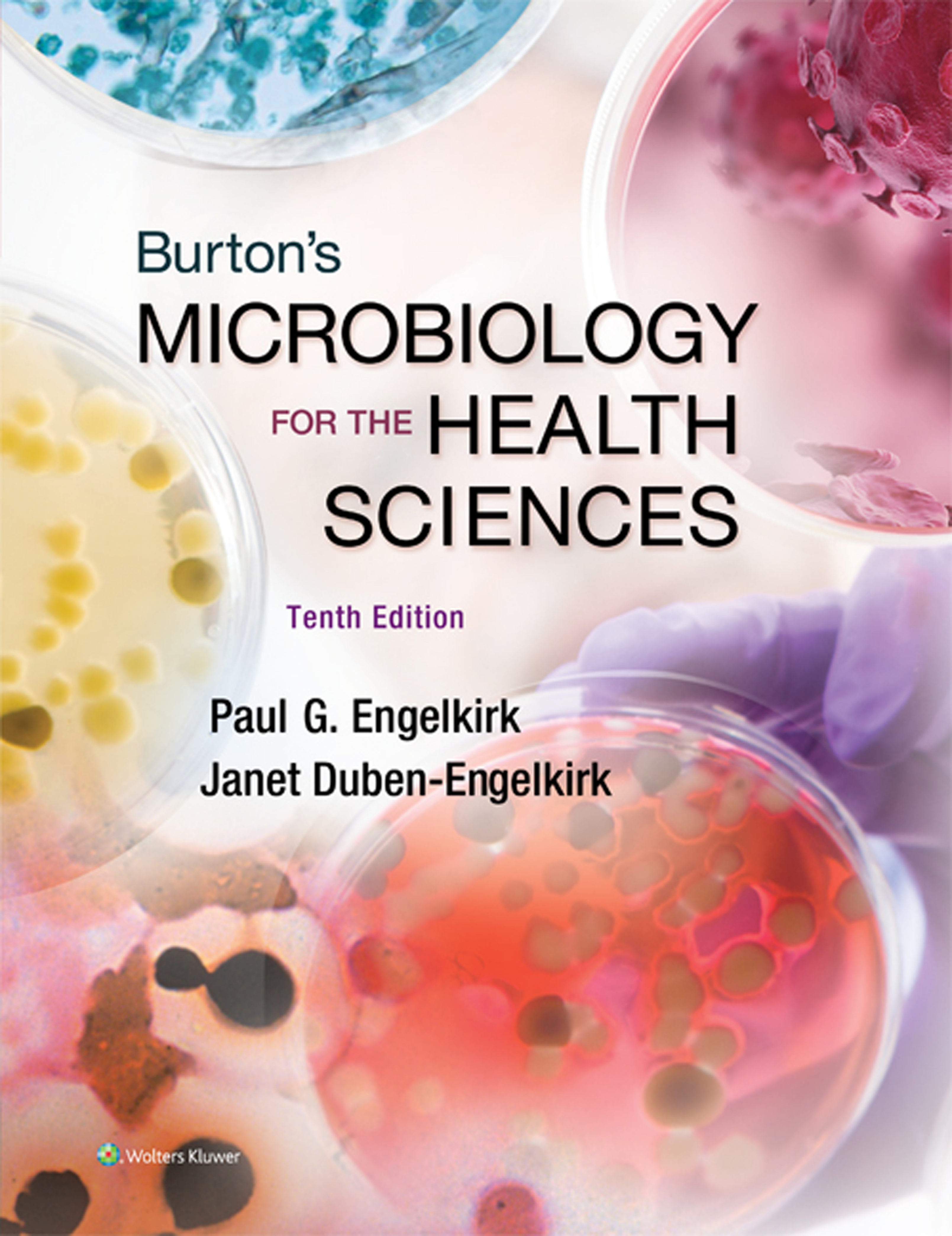

Burton's MICROBIOLOGY FOR THE HEALTH SCIENCES

Tenth Edition

Paul G. Engelkirk
Janet Duben-Engelkirk

Wolters Kluwer

BURTON'S Microbiology for the Health Sciences

TENTH EDITION

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**Dedicated to our parents,
teachers, mentors, colleagues,
and friends who have encouraged
and helped us to fulfill our dreams.**

About the Authors

Paul G. Engelkirk, PhD, MT(ASCP), SM(NRCM), is a retired professor of biological sciences from the Science Department at Central Texas College in Killeen, Texas, where he taught introductory microbiology for 12 years. Before joining Central Texas College, he was an associate professor at the University of Texas Health Science Center in Houston, Texas, where he taught diagnostic microbiology to medical laboratory science students for 8 years. Prior to his teaching career, Dr. Engelkirk served 22 years as an officer in the U.S. Army Medical Department, supervising various immunology, clinical pathology, and microbiology laboratories in Germany, Vietnam, and the United States. He retired from the Army with the rank of Lieutenant Colonel.

Dr. Engelkirk received his bachelor's degree in biology from New York University and his master's and doctorate degrees (both in microbiology and public health) from Michigan State University. He received additional medical technology and tropical medicine training at Walter Reed Army Hospital in Washington, D.C., and specialized training in anaerobic bacteriology, mycobacteriology, and virology at the Centers for Disease Control and Prevention in Atlanta, Georgia.

Dr. Engelkirk is an author of four microbiology textbooks, 10 additional book chapters, five medical laboratory-oriented self-study courses, and many scientific articles. He also served for 14 years as coeditor of four separate newsletters for clinical microbiology laboratory personnel. Dr. Engelkirk has been engaged in various aspects of clinical microbiology for over 50 years and is a past president of the Rocky Mountain Branch of the American Society for Microbiology. He and his wife, Janet, currently provide biomedical educational services through their consulting business, Biomedical Educational Services (Biomed Ed), located in Round Rock, Texas. Dr. Engelkirk's hobbies include traveling, hiking, nature photography, writing, and relaxing on his back deck.

Janet Duben-Engelkirk, EdD, MT(ASCP), has over 40 years of experience in clinical laboratory science and higher education. She received her bachelor's degrees in biology and medical technology and her master's degree in technical education from the University of Akron. She obtained her doctorate in allied health education and administration from a combined program at the University of Houston and Baylor College of Medicine in Houston, Texas.

Dr. Duben-Engelkirk began her career in clinical laboratory science education teaching students "on the bench" in a medical center hospital in Akron, Ohio. She then became Senior Education Coordinator and Associate Professor for the Clinical Laboratory Science Program at the University of Texas Health Science Center at Houston, where she taught clinical chemistry and related subjects for 12 years. In 1992, Dr. Duben-Engelkirk assumed the position of Director of Allied Health and Clinical Laboratory Science Education at Scott and White Hospital in Temple, Texas, wherein her responsibilities included teaching microbiology and clinical chemistry. In 2006, Dr. Duben-Engelkirk assumed the position of chair of the biotechnology department at the Texas Bioscience Institute and Temple College, where she was responsible for curriculum development and administration of the biotechnology degree programs. As a result of her efforts, the college received the prestigious Bellwether Award for innovative programs or practices. She and her husband, Paul, are currently co-owners of a biomedical educational consulting business.

Dr. Duben-Engelkirk was coeditor of a widely used clinical chemistry textbook and has coauthored three microbiology textbooks with Paul (clinical anaerobic bacteriology; laboratory diagnosis of infectious diseases; and this book). She has authored or coauthored numerous book chapters, journal articles, self-study courses, newsletters, and other educational materials over the course of her career.

Dr. Duben-Engelkirk has received many awards during her career, including Outstanding Young Leader in Allied Health, the American Society for Clinical Laboratory Science's Omicron Sigma Award for outstanding service, and Teaching Excellence Awards. Her professional interests include instructional technology, computer-based instruction, and distance education. Dr. Duben-Engelkirk enjoys traveling, reading, writing, music, yoga, movies, hiking, and photography.

Microbiology—the study of microbes—is a fascinating subject that impacts our daily lives in numerous ways. Microbes live on us and in us and virtually everywhere around us. They are vital in many industries. Microbes are essential for the cycling and recycling of elements such as carbon, oxygen, and nitrogen, and provide most of the oxygen in our atmosphere. They are used to clean up toxic wastes. Microbes are used in genetic engineering and gene therapy. And, of course, many microbes cause disease. In recent years, the public has been bombarded with news reports about microbe-associated medical problems such as swine flu, bird flu, severe acute respiratory syndrome (SARS), hantavirus pulmonary syndrome, flesh-eating bacteria, mad cow disease, superbugs, black mould in buildings, West Nile virus, bioterrorism, anthrax, smallpox, food recalls as a result of *Escherichia coli* and *Salmonella* contamination, and epidemics of meningitis, hepatitis, influenza, tuberculosis, whooping cough, and diarrheal diseases.

Written for Healthcare Professionals

Burton's Microbiology for the Health Sciences has been written primarily for nurses and other healthcare professionals. This book provides students of these professions with vital microbiology information that will enable them to carry out their duties in an informed, safe, and efficient manner, and protect themselves and their patients from infectious diseases. It is appropriate for use in any introductory microbiology course, as it contains all of the concepts and topics recommended by the American Society for Microbiology for such courses. Unlike many of the lengthy introductory microbiology texts on the market, *all* of the material in this book can be covered in a typical undergraduate microbiology course.

Chapters of special importance to students of the healthcare professions include those dealing with disinfection and sterilization (Chapter 8), antibiotics and other antimicrobial agents (Chapter 9), epidemiology and public health (Chapter 11), healthcare-associated infections and infection control (Chapter 12), how infectious diseases are diagnosed (Chapter 13), how microbes cause disease Chapter 14), how our bodies protect us from pathogens and infectious diseases (Chapters 15 and 16), and the major viral, bacterial, fungal, and parasitic diseases of humans (Chapters 17 through 21).

New to the Tenth Edition

The most obvious changes in the tenth edition are an increased number of full-color illustrations and improvement of the artwork. The book is divided into eight major sections, containing a total of 21 chapters. Each chapter contains a Chapter Outline, Learning Objectives, Self-Assessment Exercises, and information about the contents on thePoint. Interesting historical information, in the form of "Historical Notes," is spread throughout the book and is presented in appropriate chapters. Information summarizing important bacterial pathogens has been relocated from an appendix to Chapter 19. There are more Case Studies than in the ninth edition, and these, along with their answers, are located in the book rather than on thePoint. The number of Critical Thinking questions has been increased and are located on thePoint.

Student-Friendly Features

The authors have made every attempt to create a student-friendly book. The book can be used by all types of students, including those with little or no science background and mature students returning to school after an absence of several years. It is written in a clear and concise manner. It contains more than 50 Study Aid boxes, which explain difficult concepts and similar-sounding terms. Key points are highlighted. New terms are defined in the text and are included in a Glossary at the back of the book.

Answers to Self-Assessment Exercises contained in the book can be found in Appendix A. Appendix C contains useful formulas for conversion of one type of unit to another (e.g., Fahrenheit to Celsius and vice versa). Because Greek letters are commonly used in microbiology, the Greek alphabet can be found in Appendix D.

Additional Resources

Burton's Microbiology for the Health Sciences, 10th edition, includes additional resources for both instructors and students that are available on the book's companion Web site at http://thePoint.lww.com/Engelkirk10e.

Instructor Resources

Approved adopting instructors will be given access to the following additional resources:

- Image Bank
- Test Generator
- Lesson Plans
- PowerPoint Slides
- Clinical Microbiology Laboratory Procedures Manual

- Guidelines for Handling Microorganisms in the Teaching Laboratory
- Instructor's Guide
  - Answers to Critical Thinking Questions
  - Laboratory Activities

Student Resources

Students who have purchased *Burton's Microbiology for the Health Sciences, 10th edition*, have access to the following additional resources:

- Animations covering various topics in the text
- Interactive Quiz Bank
- Student Guide
  - Additional Self-Assessment Exercises for each chapter
  - Lists of new terms in each chapter
  - Review of Key Points
  - Special "A Closer Look," "Increase Your Knowledge," and "Critical Thinking" sections to provide additional insight as well as interesting facts on selected topics from the text
- Appendix 1: Microbial Intoxications
- Appendix 2: Phyla and Medically Important Genera Within the Domain *Bacteria*
- Appendix 3: Basic Chemistry Concepts
- Appendix 4: Responsibilities of the Clinical Microbiology Laboratory
- Appendix 5: Clinical Microbiology Procedures
- Appendix 6: Preparing Solutions and Dilutions

Purchasers of the text can access the resources online at the *Burton's Microbiology for the Health Sciences, 10th edition*, Web site at http://thePoint.lww.com/Engelkirk10e. See the inside front cover of this text for more details, including the passcode you will need to gain access to the Web site.

To Our Readers

As you will discover, the concise nature of this book makes each sentence significant. Thus, you will be intellectually challenged to learn each new concept as it is presented. It is our hope that you will enjoy your study of microbiology and be motivated to further explore this exciting field, especially as it relates to your occupation. Many students who have used this textbook in their introductory microbiology course have gone on to become infection control nurses, epidemiologists, medical laboratory professionals, and microbiologists.

Our Thanks

We are deeply indebted to the late **Gwen Burton, Ph.D.**—sole author of the first four editions of this book and coauthor of the next four. Her spirit lives on in the pages of this, the tenth edition. We can only hope that she would be as proud of what her creation has become as we are. We are also grateful to all of the Lippincott Williams & Wilkins people who helped with the editing and publication of this book, including Paula Williams, Product Development Editor; Michael Nobel, Acquisitions Editor; Leah Thomson, Marketing Manager; Priscilla Crater, Production Project Manager; and Terry Mallon, Designer.

Paul G. Engelkirk, PhD, MT(ASCP), SM(NRCM)
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In today's health careers, a thorough understanding of microbiology is more important than ever. *Burton's Microbiology for the Health Sciences, Tenth Edition*, not only provides the conceptual knowledge you will need but also teaches you how to apply it. This User's Guide introduces you to the features and tools of this innovative textbook. Each feature is specifically designed to enhance your learning experience, preparing you for a successful career as a health professional.

Chapter Opener Features

The features that open each chapter are an introduction to guide you through the remainder of the lesson.

Chapter Outline

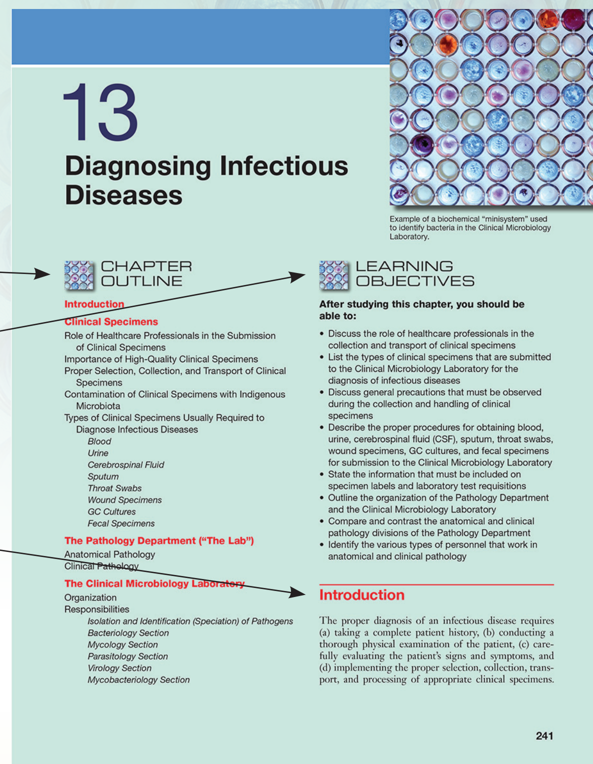
Serves as a "roadmap" to the material ahead.

Learning Objectives

Highlight important concepts—helping you to organize and prioritize learning.

Introduction

Familiarizes you with the material covered in the chapter.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Diagnosing Infectious Diseases

Example of a biochemical "minisystem" used to identify bacteria in the Clinical Microbiology Laboratory.

CHAPTER OUTLINE

Introduction

Clinical Specimens

Role of Healthcare Professionals in the Submission of Clinical Specimens

Importance of High-Quality Clinical Specimens

Proper Selection, Collection, and Transport of Clinical Specimens

Contamination of Clinical Specimens with Indigenous Microbiota

Types of Clinical Specimens Usually Required to Diagnose Infectious Diseases

Blood

Urine

Cerebrospinal Fluid

Sputum

Throat Swabs

Wound Specimens

GC Cultures

Fecal Specimens

The Pathology Department ("The Lab")

Anatomical Pathology

Clinical Pathology

The Clinical Microbiology Laboratory

Organization

Responsibilities

Isolation and Identification (Speciation) of Pathogens

Bacteriology Section

Mycology Section

Parasitology Section

Virology Section

Mycobacteriology Section

LEARNING OBJECTIVES

After studying this chapter, you should be able to:

- Discuss the role of healthcare professionals in the collection and transport of clinical specimens
- List the types of clinical specimens that are submitted to the Clinical Microbiology Laboratory for the diagnosis of infectious diseases
- Discuss general precautions that must be observed during the collection and handling of clinical specimens
- Describe the proper procedures for obtaining blood, urine, cerebrospinal fluid (CSF), sputum, throat swabs, wound specimens, GC cultures, and fecal specimens for submission to the Clinical Microbiology Laboratory
- State the information that must be included on specimen labels and laboratory test requisitions
- Outline the organization of the Pathology Department and the Clinical Microbiology Laboratory
- Compare and contrast the anatomical and clinical pathology divisions of the Pathology Department
- Identify the various types of personnel that work in anatomical and clinical pathology

Introduction

The proper diagnosis of an infectious disease requires (a) taking a complete patient history, (b) conducting a thorough physical examination of the patient, (c) carefully evaluating the patient's signs and symptoms, and (d) implementing the proper selection, collection, transport, and processing of appropriate clinical specimens.

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Chapter Features

The following features appear throughout the body of the chapter. They are designed to hone critical thinking skills and judgment, build clinical proficiency, and promote comprehension and retention of the material.

HISTORICAL NOTE

The Discovery of the Hereditary Molecule

In 1944, Oswald T. Avery and his colleagues at the Rockefeller Institute wrote one of the most important papers ever published in biology. In that paper, they announced their discovery that DNA, not proteins as had earlier been suspected, is the molecule that contains genetic information (i.e., that DNA is the hereditary molecule). They made this discovery while repeating Frederick Griffith's 1928 transformation experiments (see Chapter 7). Whereas Griffith's experiments involved mice, Avery's group conducted in vitro experiments. The importance of this discovery was not fully appreciated at the time, and Avery and his colleagues did not receive a Nobel Prize. Additional evidence that DNA is the molecule that contains genetic information was provided by Alfred Hershey and Martha Chase in 1952. Their work involved a bacteriophage that infects *E. coli*. In 1969, Hershey shared a Nobel Prize with Max Delbrück and Salvador Luria for their discoveries involving the genetic structure and replication of bacteriophages.

Historical Note Boxes

Provide insight into the history and development of microbiology and healthcare.

Spotlighting Boxes

These are a new feature spotlighting healthcare careers.

SPOTLIGHTING

Phlebotomists

As stated in the American Medical Association's Health Care Careers Directory (available under "Education," "Health Service Careers Directory" at http://www.ama-assn.org), "Phlebotomists collect, transport, handle, and process blood specimens for analysis; identify and select equipment, supplies, and additives used in blood collection; and understand factors that affect specimen collection procedures and test results. Recognizing the importance of specimen collection in the overall patient care system, phlebotomists adhere to infection control and safety policies and procedures. They practice safe blood collection and handling techniques that protect patients from injury, safeguard themselves from accidents, and produce high-quality specimens while demonstrating compassion for the patient. Phlebotomists monitor quality control within predetermined limits while demonstrating professional conduct, stress management, and communication skills with patients, peers, and other healthcare personnel as well as with the public." Information concerning educational requirements and programs, certification, and salary is available at the AMA Web site.

STUDY AID

The Central Dogma

The term "dogma" usually refers to a basic or fundamental doctrinal point in religion or philosophy. Francis Crick's use of the term "Central Dogma" refers to the most fundamental process of molecular biology—the flow of genetic information within a cell. Although originally referred to as the one gene–one protein hypothesis, it is now known that a particular gene may code for one or more proteins.

Study Aid Boxes

Summarize key information, explain difficult concepts, and differentiate similar-sounding terms.

Clinical Procedure Boxes

Set forth step-by-step instructions for common procedures.

CLINICAL PROCEDURE

CCMS Urine Collection Procedure for Female Patients

Purpose: To instruct a female in how to properly collect a CCMS urine specimen.
Equipment: Requisition, specimen label, sterile urine container, special sterile antiseptic wipes, and copy of written instructions.

Step	Rationale
1. Wash hands thoroughly.	Aids in infection control and helps avoid contamination of the site while cleaning.
2. Remove the lid of the container, being careful not to touch the inside of the cover or the container.	The lid and container must remain sterile for accurate interpretation of results.
3. Stand in a squatting position over the toilet.	Facilitates cleaning and downward flow of urine.
4. Separate the folds of skin around the urinary opening.	Allows proper cleaning of the area.

Something To Think About

These boxes contain information that will stimulate students to ponder interesting possibilities.

SOMETHING TO THINK ABOUT

"In addition to diagnosing infections caused by well-established pathogens, clinical microbiologists uncover new pathogens, acting as sentinels for possible epidemics. They also provide statistical and clinical information regarding pathogens on the scene and spur demands on research to create novel diagnostic tools. In fact, development of such tools is taking place so swiftly that, in not too many years, the practice of clinical microbiology may well become unrecognizable. Not only is the use of nucleic acid-based techniques expected to expand, but other sophisticated techniques such as mass spectrometry will make microbiological diagnoses ever more rapid and accurate."

Schaechter E. The excitement of clinical microbiology. *Microbe*. 2013;8:11–14.

Key Points

Help you pinpoint the main ideas of the text.

chemistry as part of a microbiology course. The reason why chemistry is an important component of a microbiology course is the answer to the question, "What exactly is a microorganism?" A cellular microbe can be thought of as a "bag" of chemicals that interact with each other in various ways. Even the bag itself is composed of chemicals. Everything a microorganism is and does relates to chemistry. The various ways microorganisms function and survive in their envi-

> Cells can be thought of as "bags" of chemicals. Even the bags themselves are composed of chemicals.

Self-Assessment Exercises

Help you gauge your understanding of what you have learned.

Self-Assessment Exercises

After studying this chapter, answer the following multiple-choice questions.

1. Molecules of extrachromosomal DNA are also known as:
   a. Golgi bodies
   b. lysosomes
   c. plasmids
   d. plastids
2. A bacterium possessing a tuft of flagella at one end of its cell would be called what kind of bacterium?
   a. amphitrichous
   b. lophotrichous
   c. monotrichous
   d. peritrichous

ON thePoint

- Terms Introduced in This Chapter
- Review of Key Points
- Spotlighting: Asexual versus Sexual Reproduction; Life Cycles; Eukaryotic Cell Reproduction (Mitosis and Meiosis)
- The Origin of Mitochondria and Chloroplasts
- Increase Your Knowledge
- Critical Thinking
- Additional Self-Assessment Exercises

On thePoint Boxes

Directs you to additional content and exercises for review on thePoint. Included are the following features that help reinforce and review the material covered in the book.

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The authors, editors, and publisher have exerted every effort to ensure that drug selection and dosage set forth in this text are in accordance with the current recommendations and practice at the time of publication. However, in view of ongoing research, changes in government regulations, and the constant flow of information relating to drug therapy and drug reactions, the reader is urged to check the package insert for each drug for any change in indications and dosage and for added warnings and precautions. This is particularly important when the recommended agent is a new or infrequently employed drug.

Some drugs and medical devices presented in this publication have Food and Drug Administration (FDA) clearance for limited use in restricted research settings. It is the responsibility of the health care provider to ascertain the FDA status of each drug or device planned for use in their clinical practice.

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1

Microbiology—The Science

Artist rendering of an *Escherichia coli (E. coli)* bacterial cell, one of the most thoroughly studied of all microbes.

CHAPTER OUTLINE

Introduction

What Is Microbiology?

Why Study Microbiology?

First Microorganisms on Earth

Earliest Known Infectious Diseases

Pioneers in the Science of Microbiology

Anton van Leeuwenhoek
Louis Pasteur
Robert Koch
Koch's Postulates
Exceptions to Koch's Postulates

Careers in Microbiology

Medical and Clinical Microbiology

LEARNING OBJECTIVES

After studying this chapter, you should be able to:

- Define microbiology, pathogen, nonpathogen, and opportunistic pathogen
- Differentiate between acellular microbes and microorganisms and list several examples of each
- List several reasons why microbes are important (e.g., as a source of antibiotics)
- Explain the relationship between microbes and infectious diseases
- Differentiate between infectious diseases and microbial intoxications
- List some of the contributions of Leeuwenhoek, Pasteur, and Koch to microbiology
- Differentiate between biogenesis and abiogenesis
- Explain the germ theory of disease
- Outline Koch's Postulates and cite some circumstances in which they may not apply
- Discuss two medically related fields of microbiology

Introduction

Welcome to the fascinating world of microbiology, where you will learn about creatures so small that the vast majority cannot be seen with the naked eye. In this chapter, you will discover the effects that these tiny creatures have on our daily lives, the ecosystems, and the environment around us, and why knowledge of them is of great importance to healthcare professionals. You will learn that some of them are our friends, whereas others are our enemies. You are about to embark on an exciting journey. Enjoy the adventure!

What Is Microbiology?

> Microbiology is the study of microbes. With only rare exceptions, individual microbes can be observed only with the use of various types of microscopes.

The study of microbiology is essentially an advanced biology course. Ideally, students taking microbiology will have some background in biology. Although **biology** is the study of *living* organisms (from *bios*, referring to living organisms, and *logy*, meaning "the study of"), microbiology includes the study of certain nonliving entities as well as certain living organisms. Collectively, these nonliving entities and living organisms

The two major categories of microbes are called acellular microbes (also called infectious particles) and cellular microbes (also called microorganisms). Acellular microbes include viruses and prions. Cellular microbes include all bacteria, all archaea, all protozoa, some algae, and some fungi.

are called **microbes**. *Micro* means very small—anything so small that it must be viewed with a **microscope** (an optical instrument used to observe very small objects). Therefore, **microbiology** can be defined as the *study of microbes*. With only rare exceptions (described in Chapter 4), individual microbes can be observed only with the use of various types of microscopes. Microbes are said to be *ubiquitous*, meaning they are virtually everywhere.

The various categories of microbes include viruses, bacteria, archaea, protozoa, and certain types of algae and fungi (Fig. 1-1). These categories of microbes are discussed in detail in Chapters 4 and 5. Because most scientists do not consider viruses to be living organisms, they are often referred to as "acellular microbes" or "infectious particles" rather than microorganisms.

Your first introduction to microbes may have been when your mother warned you about "germs" (Fig. 1-2). Although not a scientific term, germs are the microbes that cause disease. Your mother worried that you might become infected with these types of microbes. Disease-causing microorganisms are technically known as **pathogens** (also referred to as infectious agents) (Table 1-1). Actually, only about

Microbes that cause disease are known as pathogens. Those that do not cause disease are called nonpathogens.

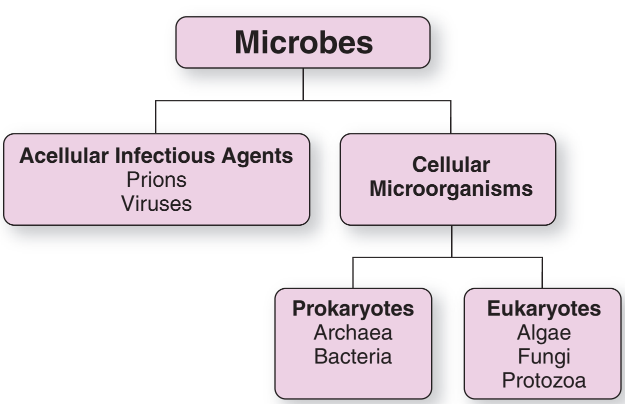

Figure 1-1. Acellular and cellular microbes. Acellular microbes (also known as infectious particles) include prions and viruses. Cellular microbes include the less complex **prokaryotes** (organisms composed of cells that lack a true nucleus, such as archaea and bacteria) and the more complex **eukaryotes** (organisms composed of cells that contain a true nucleus, such as algae, protozoa, and fungi). Prokaryotes and eukaryotes are discussed more fully in Chapter 3.

Figure 1-2. "Germs." In all likelihood, your mother was your first microbiology instructor. Not only did she alert you to the fact that there were "invisible" critters in the world that could harm you, she also taught you the fundamentals of hygiene—like hand washing.

3% of known microbes are capable of causing disease (i.e., only about 3% are pathogenic). Thus, the vast majority of known microbes are **nonpathogens**—microbes that do not cause disease. Some nonpathogens are beneficial to us, whereas others have no effect on us at all. In newspapers and on television, we read and hear more about pathogens than we do about nonpathogens, but in this book you will learn about both categories—the microbes that help us ("microbial allies") and those that harm us ("microbial enemies").

Why Study Microbiology?

Although they are very small, microbes play significant roles in our lives. Listed below are a few of the many reasons to take a microbiology course and to learn about microbes:

- We have, living on and in our bodies (e.g., on our skin and in our mouths and intestinal tract), approximately 10 times as many microbes as the total number of cells (i.e., epithelial cells, nerve cells, muscle cells, etc.) that make up our bodies (10 trillion cells × 10 = 100 trillion microbes). It has been estimated

The microbes that live on and in the human body are referred to as our indigenous microbiota.

Table 1-1 Pathogens

Category	Examples of Diseases They Cause
Algae	A very rare cause of infections, but they can cause intoxications (which result from ingestion of toxins)
Bacteria	Anthrax, botulism, cholera, diarrhea, diphtheria, ear and eye infections, food poisoning, gas gangrene, gonorrhea, hemolytic uremic syndrome (HUS), intoxications, Legionnaires disease, leprosy, Lyme disease, meningitis, plague, pneumonia, spotted fever, scarlet fever rickettsiosis, staph infections, strep throat, syphilis, tetanus, tuberculosis, tularemia, typhoid fever, typhus, urethritis, urinary tract infections, whooping cough
Fungi	Allergies, cryptococcosis, histoplasmosis, intoxications, meningitis, pneumonia, thrush, tinea (ringworm) infections, yeast vaginitis
Protozoa	African sleeping sickness, amebic dysentery, babesiosis, Chagas disease, cryptosporidiosis, diarrhea, giardiasis, malaria, meningoencephalitis, pneumonia, toxoplasmosis, trichomoniasis
Viruses	AIDS, "bird flu," certain types of cancer, chickenpox, cold sores (fever blisters), common cold, dengue, diarrhea, encephalitis, genital herpes infections, German measles, hantavirus pulmonary syndrome (HPS), hemorrhagic fevers, hepatitis, infectious mononucleosis, influenza, measles, meningitis, monkeypox, mumps, pneumonia, polio, rabies, severe acute respiratory syndrome (SARS), shingles, smallpox, "swine flu," warts, yellow fever

that perhaps as many as 500 to 1,000 different species of microbes live on and in us. Collectively, these microbes are known as our **indigenous microbiota** (or human microbiome or human bioneme)[a] and, for the most part, they are of benefit to us. For example, the indigenous microbiota inhibit the growth of pathogens in those areas of the body where they live by occupying space, depleting the food supply, and secreting materials (waste products, toxins, antibiotics, etc.) that may prevent or reduce the growth of pathogens. Indigenous microbiota are discussed more fully in Chapter 10.

- Some of the microbes that colonize (inhabit) our bodies are known as **opportunistic pathogens** (or *opportunists*). Although these microbes usually do not cause us any problems, they have the potential to cause infections if they gain access to a part of our anatomy where they do not belong. For example, a bacterium called *Escherichia coli* (*E. coli*) lives in our intestinal tracts. This organism does not cause us any harm as long as it remains in our intestinal tract, but can cause disease if it gains access to our urinary bladder, bloodstream, or a wound. Other opportunistic pathogens strike when a person becomes run-down, stressed out, or debilitated (weakened) as a result of some disease or condition. Thus, opportunistic pathogens can be thought of as microbes awaiting the opportunity to cause disease.

> Opportunistic pathogens do not cause disease under ordinary conditions, but have the potential to cause disease should the opportunity present itself.

- Microbes are essential for life on this planet as we know it. For example, some microbes produce oxygen by the process known as **photosynthesis** (discussed in Chapter 7). Actually, microbes contribute more oxygen to our atmosphere than do plants. Thus, organisms that require oxygen—humans, for example—owe a debt of gratitude to the algae and cyanobacteria (a group of photosynthetic bacteria) that produce oxygen.
- Many microbes are involved in the decomposition of dead organisms and the waste products of living organisms. Collectively, these microbes are referred to as **decomposers** or **saprophytes**. Decomposition is the process by which substances are broken down into simpler forms of matter. By definition, a saprophyte is an organism that lives on dead or decaying organic matter. Imagine living in a world with no decomposers. Not a pleasant thought! Saprophytes aid in fertilization by returning inorganic nutrients to the soil. They break down dead and dying organic materials (plants and animals) into nitrates, phosphates, and other chemicals necessary for the growth of plants (Fig. 1-3).
- Some microbes are capable of decomposing industrial wastes (oil spills, for example). Thus, we can use microbes—genetically engineered microbes, in some cases—to clean up after ourselves. The use of microbes in this manner is called **bioremediation**, a topic discussed in more detail in Chapter 10. **Genetic engineering** is discussed briefly in a following section and more fully in Chapter 7.
- Many microbes are involved in elemental cycles, such as the carbon, nitrogen, oxygen, sulfur, and phosphorous cycles. In the nitrogen cycle, certain bacteria convert nitrogen gas in the air to ammonia in the soil. Other soil bacteria then convert the ammonia to nitrites and nitrates. Still other bacteria convert the nitrogen in nitrates to nitrogen gas, thus completing the cycle (Fig. 1-4). Knowledge of these microbes is important to farmers who practice crop rotation to

[a]Use of the older terms "normal flora" and "indigenous microflora" is discouraged because "flora" refers to plants. Microbes are *not* plants.

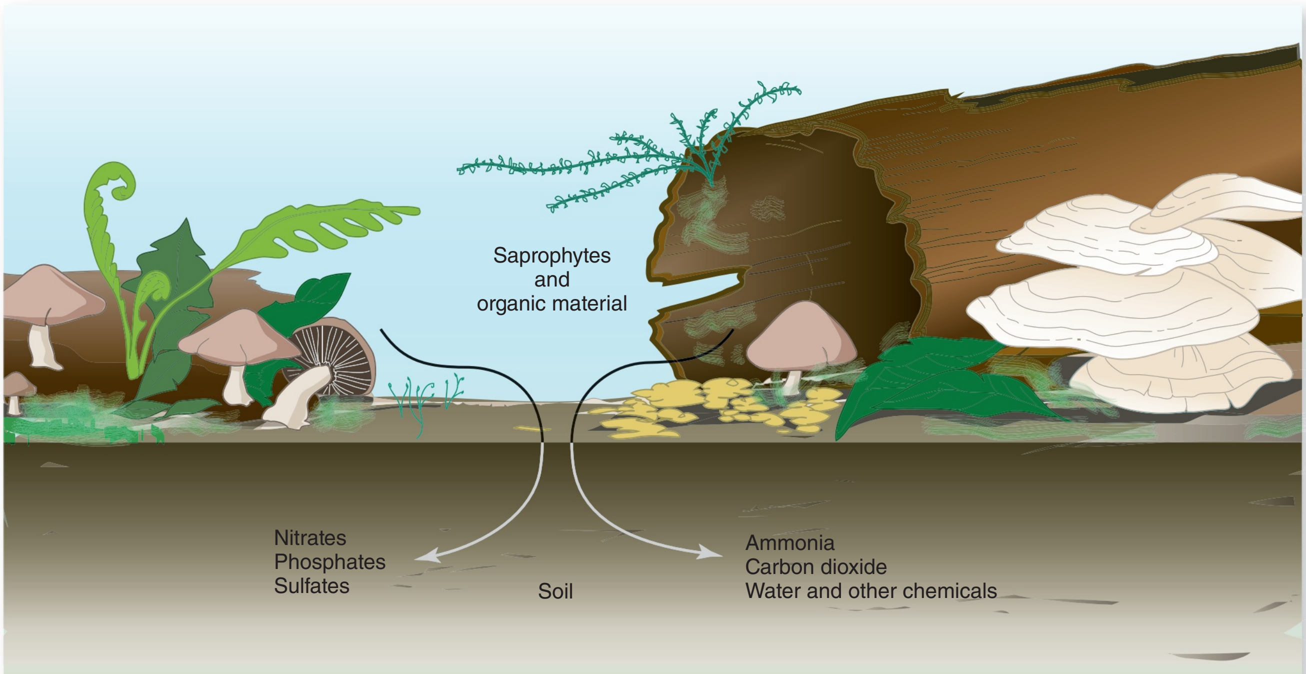

Figure 1-3. Saprophytes. Saprophytes break down dead and decaying organic material into inorganic nutrients in the soil.

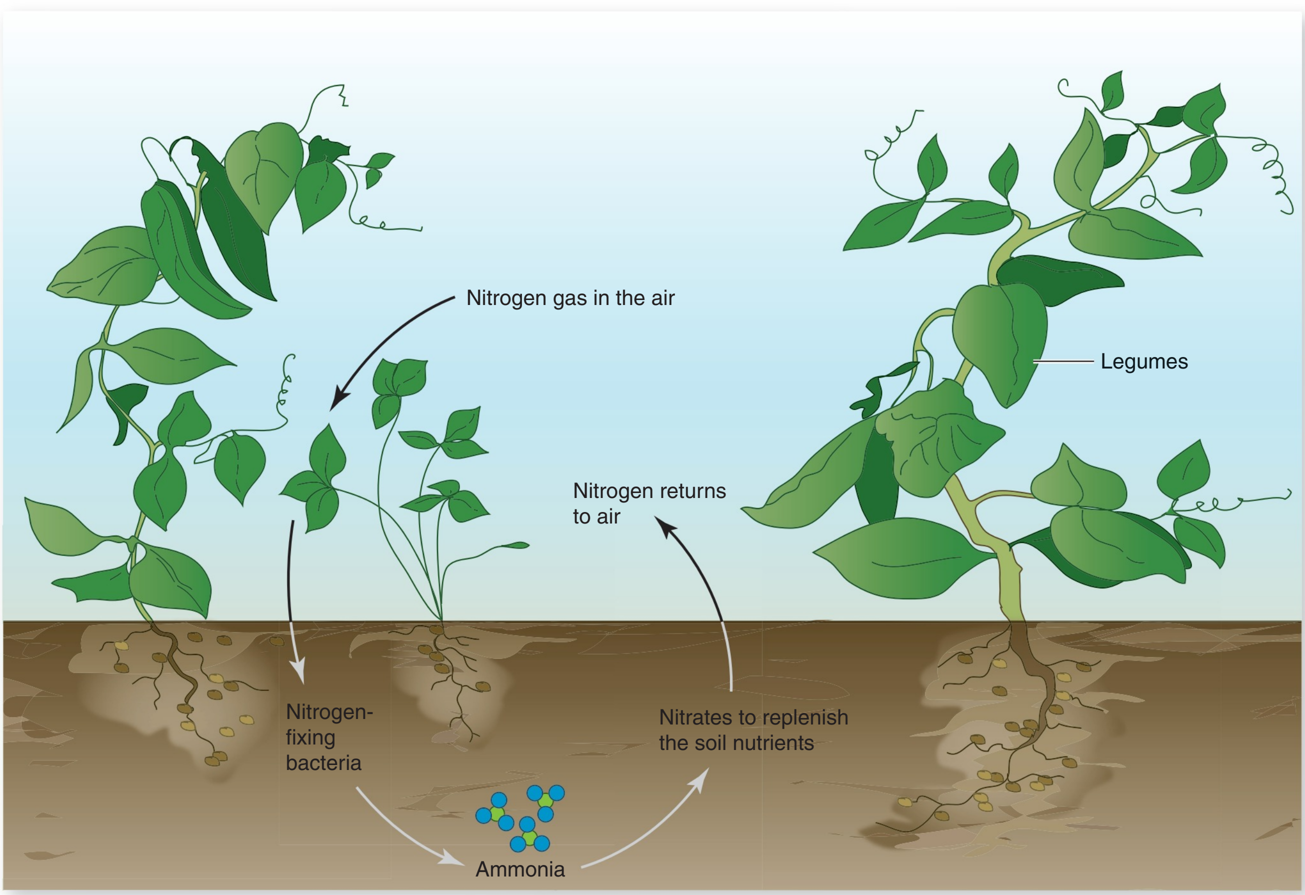

Figure 1-4. Nitrogen fixation. Nitrogen-fixing bacteria that live on or near the roots of legumes convert free nitrogen from the air into ammonia in the soil. Nitrifying bacteria then convert the ammonia into nitrites and nitrates, which are nutrients used by plants.

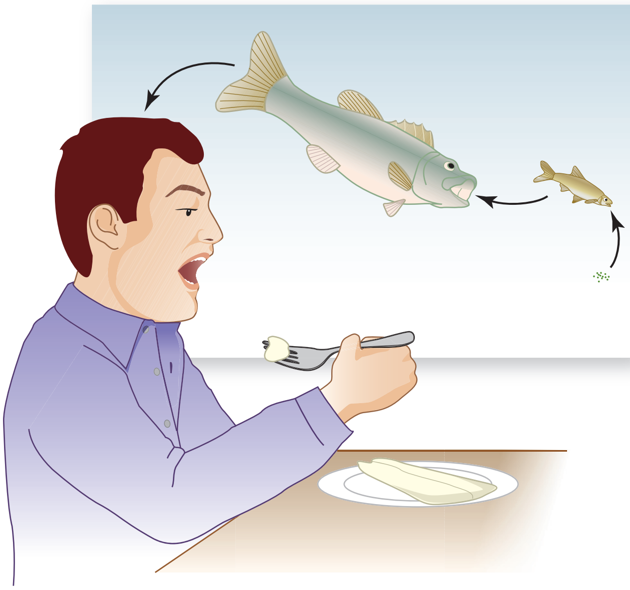

Figure 1-5. Food chain. Tiny living organisms such as bacteria, algae, microscopic aquatic plants (e.g., phytoplankton), and microscopic aquatic animals (e.g., zooplankton) are eaten by larger animals, which in turn are eaten by still larger animals, etc., until an animal in the chain is consumed by a human. Humans are at the top of the food chain.

replenish nutrients in their fields and to gardeners who keep compost pits as a source of natural fertilizer. In both cases, dead organic material is broken down into inorganic nutrients (e.g., nitrates and phosphates) by microbes. The study of the relationships between microbes and the environment is called **microbial ecology**. Microbial ecology and the nitrogen cycle are discussed more fully in Chapter 10.

- Algae and bacteria serve as food for tiny animals. Then, larger animals eat the smaller creatures, and so on. Thus, microbes serve as important links in food chains (Fig. 1-5). Microscopic organisms in the ocean, collectively referred to as **plankton**, serve as the starting point of many food chains. Tiny marine plants and algae are called **phytoplankton**, whereas tiny marine animals are called **zooplankton**.
- Some microbes live in the intestinal tracts of animals, where they aid in the digestion of food and, in some cases, produce substances that are of value to the host animal. For example, the *E. coli* bacteria that live in the human intestinal tract produce vitamins K and B_1, which are absorbed and used by the human body. Although termites eat wood, they cannot digest wood. Fortunately for them, termites have cellulose-eating protozoa in their intestinal tracts that break down the wood that the termites consume into smaller molecules that the termites can use as nutrients.
- Many microbes are essential in various food and beverage industries, whereas others are used to produce certain enzymes and chemicals (Table 1-2). The use of living organisms or their derivatives to make or modify useful products or processes is called **biotechnology**, an exciting and timely topic that is discussed more fully in Chapter 10.
- Some bacteria and fungi produce antibiotics that are used to treat patients with infectious diseases. By definition, an **antibiotic** is a substance produced by a microbe that is effective in killing or inhibiting the growth of other microbes. The use of microbes in the antibiotic industry is an example of biotechnology. Production of antibiotics by microbes is discussed in Chapter 9.
- Microbes are essential in the field of genetic engineering. In genetic engineering, a gene or genes from one organism (e.g., from a bacterium, a human, an animal, or a plant) is/are inserted into a bacterial or yeast cell. Because a gene contains the instructions for the production of a gene product (usually a protein), the cell that receives a new gene can now produce whatever product is coded for by that gene; so too can all of the cells that arise from the original cell. Microbiologists have engineered bacteria and yeasts to produce a variety of useful substances, such as insulin, various types of growth hormones, interferons, and materials for use as vaccines. Genetic engineering is discussed more fully in Chapter 7.
- For many years, microbes have been used as "cell models." The more the scientists learned about the

Table 1-2 Products Requiring Microbial Participation in the Manufacturing Process

Category	Examples
Foods	Acidophilus milk, bread, butter, buttermilk, chocolate, coffee, fish sauces, green olives, kimchi (from cabbage), meat products (e.g., country-cured hams, sausage, salami), pickles, poi (fermented taro root), sauerkraut, sour cream, sourdough bread, soy sauce, various cheeses (e.g., cottage cheese, cream cheese, cheddar, Swiss, Limburger, Camembert, Roquefort, and other blue cheeses), vinegar, yogurt
Alcoholic beverages	Ale, beer, brandy, sake (rice wine), rum, sherry, vodka, whiskey, wine
Chemicals	Acetic acid, acetone, butanol, citric acid, ethanol, formic acid, glycerol, isopropanol, lactic acid
Antibiotics	Amphotericin B, bacitracin, cephalosporins, chloramphenicol, cycloheximide, cycloserine, erythromycin, griseofulvin, kanamycin, lincomycin, neomycin, novobiocin, nystatin, penicillin, polymyxin B, streptomycin, tetracycline

structure and functions of microbial cells, the more they learned about cells in general. The intestinal bacterium *E. coli* is one of the most studied of all microbes. By studying *E. coli*, scientists have learned a great deal about the composition and inner workings of cells, including human cells.

- Finally, we come to diseases. Microbes cause two categories of diseases: infectious diseases and microbial intoxications (Fig. 1-6). An **infectious disease** results when a pathogen colonizes the body and subsequently causes disease. A **microbial intoxication** results when a person ingests a *toxin* (poisonous substance) that has been produced by a microbe. Of the two categories, infectious diseases cause far more illnesses and deaths. Infectious diseases are the leading cause of death in the world and the third leading cause of death in the United States (after heart disease and cancer). Worldwide, infectious diseases cause about 50,000 deaths per day, with the majority of deaths occurring in developing countries. Anyone pursuing a career in a healthcare profession must be aware of infectious diseases, the pathogens that cause them, the sources of the pathogens, how these diseases are transmitted, and how to protect yourself and your patients from these diseases. Physicians' assistants, nurses, surgical technologists, dental assistants, laboratory scientists, respiratory therapists, orderlies, nurses' aides, and all others who are associated with patients and patient care must take precautions to prevent the spread of pathogens. Harmful microbes may be transferred from healthcare workers to patients; from patient to patient; from contaminated mechanical devices, instruments, and syringes to patients; from contaminated bedding, clothes, dishes, and food to patients; and from patients to healthcare workers, hospital visitors, and other susceptible persons. To limit the spread of pathogens, sterile, aseptic, and antiseptic techniques (discussed in Chapter 12) are used everywhere in hospitals, nursing homes, operating rooms, and laboratories. In addition, the bioterrorist activities of recent years serve to remind us that everyone should have an understanding of the agents (pathogens) that are involved and how to protect ourselves from becoming infected. Bioterrorist and biological warfare agents are discussed in Chapter 11. Additional information about microbial intoxications can be found in Appendix 1 on thePoint: "Microbial Intoxications."

Pathogens cause two major types of diseases: infectious diseases and microbial intoxications.

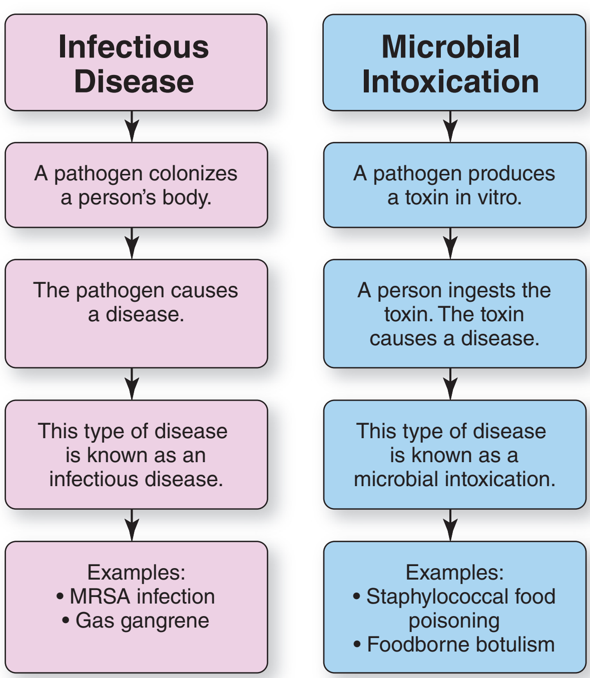

Figure 1-6. The two categories of diseases caused by pathogens. Infectious diseases result when a pathogen colonizes (inhabits) the body and subsequently causes disease. Microbial intoxications result when a person ingests a toxin (poisonous substance) that has been produced by a pathogen in vitro (outside the body). MRSA, methicillin-resistant *Staphylococcus aureus*.

First Microorganisms on Earth

Perhaps you have wondered how long microbes have existed on Earth. Scientists tell us that Earth was formed about 4.5 billion years ago and, for the first 800 million to 1 billion years of Earth's existence, there was no life on this planet. Fossils of primitive microbes (as many as 11 different types) found in ancient sandstone formations in northwestern Australia date back to about 3.5 billion years ago. By comparison, animals and humans are relative newcomers. Animals made their appearance on Earth between 900 and 650 million years ago (there is some disagreement in the scientific community about the exact date), and, in their present form, humans (*Homo sapiens*) have existed for only the past 100,000 years or so. Candidates for the first microbes on Earth are archaea and cyanobacteria; these types of microbes are discussed in Chapter 4.

Earliest Known Infectious Diseases

In all likelihood, infectious diseases of humans and animals have existed for as long as humans and animals have inhabited the planet. We know that human pathogens have existed for thousands of years because damage caused by them has been observed in the bones and internal organs of mummies and early human fossils. By studying mummies, scientists have learned that bacterial diseases, such as tuberculosis, leprosy, and syphilis, malaria, hepatitis, and parasitic worm infections, such as schistosomiasis, dracunculiasis (guinea worm infection), hookworm, and fluke and tapeworm infections, have been around for a very long time.

The earliest known account of a "pestilence" occurred in Egypt about 3180 BC. This may represent the first recorded epidemic, although words such as *pestilence* and *plague* were used without definition in early writings. Around 1900 BC, near the end of the Trojan War, the Greek army was decimated by an epidemic of what is thought to have been bubonic plague. The Ebers papyrus, describing epidemic fevers, was discovered in a tomb in Thebes, Egypt; it was written around 1500 BC. A disease thought to be smallpox occurred in China around 1122 BC. Epidemics of plague occurred in Rome in 790, 710, and 640 BC, and in Greece around 430 BC.

In addition to the diseases already mentioned, there are early accounts of rabies, anthrax, dysentery, smallpox, ergotism, botulism, measles, typhoid fever, typhus fever, diphtheria, and syphilis. The syphilis story is quite interesting. It made its first appearance in Europe in 1493. Many people believe that syphilis was carried to Europe by Native Americans who were brought to Portugal by Christopher Columbus. The French called syphilis the *Neapolitan disease*; the Italians called it the *French or Spanish disease*; and the English called it the *French pox*. Other names for syphilis were Spanish, German, Polish, and Turkish pocks. The name "syphilis" was not given to the disease until 1530.

Pioneers in the Science of Microbiology

Bacteria and protozoa were the first microbes to be observed by humans. It then took about 200 years before a connection was established between microbes and infectious diseases. Among the most significant events in the early history of microbiology were the development of microscopes, bacterial staining procedures, techniques that enabled microorganisms to be cultured (grown) in the laboratory, and steps that could be taken to prove that specific microbes were responsible for causing specific infectious diseases. During the past 400 years, many individuals contributed to our present understanding of microbes. Three early microbiologists are discussed in this chapter; others are discussed at appropriate points throughout the book.

Anton van Leeuwenhoek (1632–1723)

Because Anton van Leeuwenhoek was the first person to see live bacteria and protozoa, he is sometimes referred to as the "Father of Microbiology," the "Father of Bacteriology," and the "Father of Protozoology."[b] Interestingly, Leeuwenhoek was not a trained scientist. At various times in his life, he was a fabric merchant, a surveyor, a wine assayer, and a minor city official in Delft, Holland. As a hobby, he ground tiny glass lenses, which he mounted in small metal frames, thus creating what today are known as **single-lens microscopes** or **simple microscopes**. During his lifetime, he made more than 500 of these microscopes. Leeuwenhoek's fine art of grinding lenses that would magnify an object to 200 to 300 times its size was lost at his death because he had not taught this skill to anyone during his lifetime. In one of the hundreds of letters that he sent to the Royal Society of London, he wrote:

> My method for seeing the very smallest animalcules I do not impart to others; nor how to see very many animalcules at one time. This I keep for myself alone.

Apparently, Leeuwenhoek had an unquenchable curiosity, as he used his microscopes to examine almost anything he could get his hands on (Fig. 1-7). He examined

Figure 1-7. Portrait of Anton van Leeuwenhoek by Jan Verkolje. (Courtesy of Wikipedia.)

[b]Although Leeuwenhoek was probably the first person to see live protozoa, he may not have been the first person to observe protozoa. Many scholars believe that Robert Hooke (1635–1703), an English physician, was the first person to observe and describe microbes, including a fossilized protozoan and two species of live microfungi.

scrapings from his teeth, water from ditches and ponds, water in which he had soaked peppercorns, blood, sperm, and even his own diarrheal stools. In many of these specimens, he observed various tiny living creatures, which he called "animalcules." He recorded his observations in the form of letters, which he sent to the Royal Society of London. The following passage is an excerpt from one of those letters (*Milestones in Microbiology*, edited by Thomas Brock. American Society for Microbiology, Washington, DC, 1961):

> Tho my teeth are kept usually very clean, nevertheless when I view them in a Magnifying Glass, I find growing between them a little white matter as thick as wetted flower. . . . I therefore took some of this flower and mixt it . . . with pure rain water wherein were no Animals. and then to my great surprize perceived that the aforesaid matter contained very many small living Animals, which moved themselves very extravagantly. . . . The number of these Animals in the scurf of a mans Teeth, are so many that I believe they exceed the number of Men in a kingdom. For upon the examination of a small parcel of it, no thicker than a Horse-hair, I found too many living Animals therein, that I guess there might have been 1000 in a quantity of matter no bigger than the 1/100 part of a sand.

Leeuwenhoek's letters finally convinced scientists of the late 17th century of the existence of microbes. Leeuwenhoek never speculated on their origin, nor did he associate them with the cause of disease. Such relationships were not established until the work of Louis Pasteur and Robert Koch in the late 19th century.

The following quote is from Paul de Kruif's book, *Microbe Hunters*, Harcourt Brace, 1926:

> [Leeuwenhoek] had stolen and peeped into a fantastic sub-visible world of little things, creatures that had lived, had bred, had battled, had died, completely hidden from and unknown to all men from the beginning of time. Beasts these were of a kind that ravaged and annihilated whole races of men ten million times larger than they were themselves. Beings these were, more terrible than fire-spitting dragons or hydra-headed monsters. They were silent assassins that murdered babes in warm cradles and kings in sheltered places. It was this invisible, insignificant, but implacable—and sometimes friendly—world that Leeuwenhoek had looked into for the first time of all men of all countries.

Once scientists became convinced of the existence of tiny creatures that could not be observed with the naked eye, they began to speculate on their origin. On the basis of observation, many of the scientists of that time believed that life could develop spontaneously from inanimate substances, such as decaying corpses, soil, and swamp gases. The idea that life can arise spontaneously from nonliving material is called the theory of spontaneous generation or **abiogenesis**. For more than two centuries, from 1650 to 1850, this theory was debated and tested. Following the work of others, Louis Pasteur (discussed later) and John Tyndall (discussed in Chapter 3) finally disproved the theory of spontaneous generation and proved that life can only arise from preexisting life. This is called the theory of **biogenesis**, first proposed by a German scientist named Rudolf Virchow in 1858. Note that the theory of biogenesis does not speculate on the *origin* of life, a subject that has been discussed and debated for hundreds of years.

Louis Pasteur (1822–1895)

Louis Pasteur (Fig. 1-8), a French chemist, made numerous contributions to the newly emerging field of microbiology, and, in fact, his contributions are considered by many people to be the foundation of the science of microbiology and a cornerstone of modern medicine. Listed below are some of his most significant contributions:

- While attempting to discover why wine becomes contaminated with undesirable substances, Pasteur

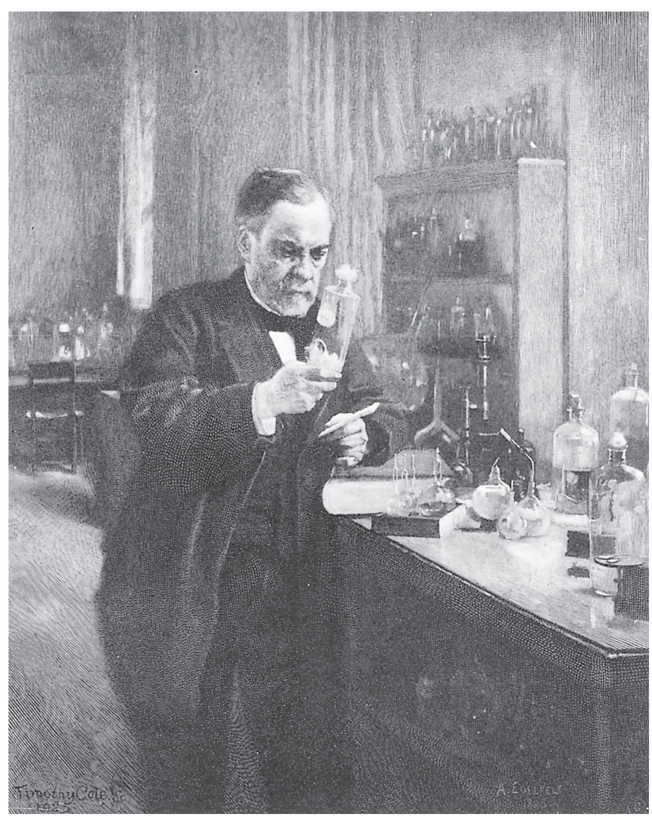

Figure 1-8. Pasteur in his laboratory. A 1925 wood engraving by Timothy Cole. (From Zigrosser C. *Medicine and the Artist* [Ars Medica]. New York: Dover Publications, Inc.; 1970. With permission from the Philadelphia Museum of Art.)

discovered what occurs during alcoholic fermentation (discussed in Chapter 7). He also demonstrated that different types of microbes produce different fermentation products. For example, yeasts convert the glucose in grapes to ethyl alcohol (ethanol) by fermentation, but certain contaminating bacteria, such as *Acetobacter*, convert glucose to acetic acid (vinegar) by fermentation, thus, ruining the taste of the wine.

- Through his experiments, Pasteur dealt the fatal blow to the theory of spontaneous generation.
- Pasteur discovered forms of life that could exist in the absence of oxygen. He introduced the terms "aerobes" (organisms that require oxygen) and "anaerobes" (organisms that do not require oxygen).
- Pasteur developed a process (today known as pasteurization) to kill microbes that were causing wine to spoil—an economic concern to France's wine industry. **Pasteurization** can be used to kill pathogens in many types of liquids. Pasteur's process involved heating wine to 55°C[c] and holding it at that temperature for several minutes. Today, pasteurization is accomplished by heating liquids to 63°C to 65°C for 30 minutes or to 73°C to 75°C for 15 seconds. It should be noted that pasteurization does not kill *all* of the microbes in liquids—just the pathogens.
- Pasteur discovered the infectious agents that caused the silkworm diseases that were crippling the silk industry in France. He also discovered how to prevent such diseases.
- Pasteur made significant contributions to the germ theory of disease—the theory that specific microbes cause specific infectious diseases. For example, anthrax is caused by a specific bacterium (*Bacillus anthracis*), whereas tuberculosis is caused by a different bacterium (*Mycobacterium tuberculosis*).
- Pasteur championed changes in hospital practices to minimize the spread of disease by pathogens.
- Pasteur developed vaccines to prevent chicken cholera, anthrax, and swine erysipelas (a skin disease). It was the development of these vaccines that made him famous in France. Before the vaccines, these diseases were decimating chickens, sheep, cattle, and pigs in that country—a serious economic problem.
- Pasteur developed a vaccine to prevent rabies in dogs and successfully used the vaccine to treat human rabies. (See the following Historical Note.)

To honor Pasteur and continue his work, especially in the development of a rabies vaccine, the Pasteur Institute was created in Paris in 1888. It became a clinic for rabies treatment, a research center for infectious diseases, and a teaching center. Many scientists who studied under Pasteur went on to make important discoveries of their own and create a vast international network of Pasteur Institutes. The first of the foreign institutes was founded in Saigon, Vietnam, which is today known as Ho Chi Minh City. One of the directors of that institute was Alexandre Emile Jean Yersin—a former student of Robert Koch and Louis Pasteur—who, in 1894, discovered the bacterium that causes plague.

HISTORICAL NOTE

An Ethical Dilemma for Louis Pasteur

In July 1885, while he was developing a vaccine that would prevent rabies in dogs, Louis Pasteur faced an ethical decision. A 9-year-old boy, named Joseph Meister, had been bitten 14 times on the legs and hands by a rabid dog. At the time, it was assumed that virtually anyone who was bitten by a rabid animal would die. Meister's mother begged Pasteur to use his vaccine to save her son. Pasteur was a chemist, not a physician, and thus was not authorized to treat humans. Also, his experimental vaccine had never been administered to a human being. Nonetheless, 2 days after the boy had been bitten, Pasteur injected Meister with the vaccine in an attempt to save the boy's life. The boy survived, and Pasteur realized that he had developed a rabies vaccine that could be administered to a person after he or she had been infected with rabies virus.

Robert Koch (1843–1910)

Robert Koch (Fig. 1-9), a German physician, made numerous contributions to the science of microbiology. Some of them are listed here:

- Koch made many significant contributions to the germ theory of disease. For example, he proved that the anthrax bacillus (*B. anthracis*), which had been discovered earlier by other scientists, was truly the causative agent of anthrax. He accomplished this using a series of scientific steps that he and his colleagues had developed; these steps later became known as Koch's Postulates (described later in this chapter).
- Koch discovered that *B. anthracis* produces spores, capable of resisting adverse conditions.
- Koch developed methods of fixing, staining, and photographing bacteria.

[c]"C" is an abbreviation for Celsius. Although Celsius is also referred to as centigrade, Celsius is preferred. Formulas for converting Celsius to Fahrenheit and vice versa can be found in Appendix C ("Useful Conversions").